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Experimental Comparison of Passive Heating/Cooling Space in Lightweight Buildings with Potential Application in Mining Camps

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Abstract. The total energy consumption in a house in Chile includes 30% of heating expenses, increasing to 60% in the winter period. The current energy source are fossil fuels, which can be replaced by the sun, with an efficient implementation of the use of PCM for passive cooling/heating space from solar radiation, benefiting the environment. In the north of Chile there is a solar radiation index of approximately 2750 kWh·m⁻², low cloudiness and low precipitation rates, indicating an important source of energy and great opportunity for improvement in the use and management of energy resources. Moreover, mining camps present in large numbers in the northern zone require a lot of energy to cool and heat the space. This research shows the thermal behavior in summer and winter of two lightweight constructions, similar to the type used in mining camps, with dimensions of 2.5 x 2.5 x 2.5 m at pilot scale installed at the University of Antofagasta, Chile. One of these modules contains PCM on the inside of the walls and ceiling, while the other does not, to analyze the effect of PCM by comparison. The results of this work show that in winter (August) the application of PCM favors the permanence within the thermal comfort zone, with a difference of 5°C. In summer there is an opposite effect (January), experiencing a higher temperature increase inside the container with PCM, with a difference of 4°C. According to the constructive characteristics, properties and quantity of PCM used, and the effect of solar radiation on the structure and environmental conditions, there are benefits in energy saving and efficiency in the winter period, while summer shows results that enhance the study and analysis of the applied technology to solve the thermal behavior shown in this season.

1. Introduction

Current conditions and climate changes worldwide force the human being to act against this constant deterioration of the planet. The pollution of the environment has been decreasing slightly thanks to the development and search for new alternatives of renewable energy sources, since the use of non-renewable sources of fossil fuels such as coal, oil and natural gas is one of the main reasons for the emission in various amounts of different harmful gases, such as CO₂, which contribute directly to



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global warming. From the above, it is important to note that renewable energy sources have a greater benefit in their exploitation than non-renewable resources, due to their long-term availability, accessibility, and friendliness with the environment [1], such as solar energy, which is the focus of the present work. Therefore, it is possible to affirm that energy is the key requirement to achieve technological advancement and economic development for the progress of societies around the world [2], in addition to the important care of the environment.

The sun as a renewable source has a significant drawback, which corresponds to its different availability at day and night. For this reason, the development of thermal energy storage (TES) technologies and materials is raising interest. Phase change materials (PCM), used in latent heat thermal energy storage (LHTES) systems, are a group of materials capable of storing and releasing heat during the PCM phase transition cycles, which indicate a process of charge and discharge of the stored energy [3]. This happens with a chemical, thermodynamic, and cyclic stability of the material. Moreover, cyclic stability refers to the charge and discharge process occurring repeatedly (at least 5000 cycles) without varying the phase change temperature and thermophysical properties, nor the chemical composition and physicochemical properties of the material, which are thermodynamic and chemical stability, respectively.

The application of PCMs as TES for cooling and heating in buildings is well known lately, due to the cost of fossil sources and today environmental concerns [4]. Different authors investigate PCMs in constructions [5-8]. From this it follows that, in very cold or hot areas, the consumption of electricity varies greatly during the day and night, largely due to domestic demand for heating and cooling [4], highlighting that the total energy consumption in a Chilean home corresponds to 30% of heating expenses, reaching a 60% cost during the winter period [9]. This work applies an organic PCM in lightweight constructions located in Antofagasta, Chile, with construction properties similar to those existing in the mining camps of the northern region of this country, since, the integration of passive LHTES systems with PCM can increase the capacity of thermal storage of buildings, avoid overheating by thermal loads and/or solar radiation, and decrease indoor temperature variation [10]. Even more, the Antofagasta region has a solar radiation of approx. $2750 \text{ kWh}\cdot\text{m}^{-2}$, in addition of an arid and clear weather with favorable environmental conditions for the use of solar energy and the application of related technologies.

The objective of this research is to improve energy efficiency and energy savings, in addition to granting adequate use of energy resources in the Chilean mining industry during the summer and winter periods, where thermal loads make it difficult to stay in the thermal comfort zone. It is for this reason that the analysis of the thermal behavior of this type of construction with PCM is relevant, because the working conditions due to the location of the mines and the operational requirements force the mining camps to have prolonged thermal comfort and rest with high quality of sleep for their workers [11].

2. Materials and methods

Two containers with a north-facing door and window of $2.5 \times 2.5 \times 2.5 \text{ m}^3$ were installed at the University of Antofagasta, Chile (Fig. 1), one with PCM and the other without PCM to make a comparison of the thermal behavior of both constructions. The installation procedure of the cubicles is described in [12]. These lightweight buildings consist of galvanized steel, a layer mineral wool insulation, and gypsum board with/without PCM on the walls, from outside to inside. Two sensors have been installed on each wall, in addition to another located in the center of the cubicles to record the internal temperature (Fig. 2b). The location of the sensors in the walls is one to record the temperature of the inner part and another for the outside part of the last layer of the envelope (Fig. 2b), that is, the gypsum board containing or not the PCM. The organic microencapsulated PCM used is Micronal23® from BASF with a phase change temperature of approximately 23°C , with 18 wt.% included in the gypsum board of commercial name Comfortboard23.

The roof of both containers is constructed just like the walls, in addition to an air chamber after the insulating layer, before reaching the common gypsum board or Comfortboard23, as appropriate. The

floor is composed of galvanized steel and plywood in both buildings. Two sensors are installed in the same way as the walls on each roof (Fig. 2a), while another sensor is located inside the plywood of the building floor. The calibration of the Pt-100 sensors, configuration and connection with a DL01-CPU Data Logger used in this investigation, in addition to the use of the TSC-01 computer software are detailed in [12]. The operation of the temperature register is every 5 min.



Figure 1. Containers with PCM (right) and without PCM (left) installed at the University of Antofagasta, Chile.



Figure 2. Pt-100 sensors installed in (a) roof, (b) walls and in the center of the cubicles.

Table 1 shows the thermophysical properties, density and thickness of the construction materials used, since, in order to evaluate an adequate application of a PCM for a certain purpose and temperature range, it is crucial to determine its thermophysical properties [4], and the properties of building materials, to be able to know the thermal resistance, insulation capacity and thermal inertia of buildings.

Table 1. Thermophysical properties, density, and thickness of building materials.

Construction Material	Thermal conductivity [$\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$]	Thickness [m]	Density [$\text{kg}\cdot\text{m}^{-3}$]	Specific heat [$\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$]
Galvanized steel	40	0.008	7850	500
Mineral wool	0.038	0.04	32	835
Common gypsum Board	0.17	0.008	670	1089
Comfortboard23	0.23	0.0125	800	1625
Plywood	0.12	0.018	570	1380

3. Results and Discussion

Figs. 3 and 4 show the interior temperatures of the containers with/without PCM on the 13th and 14th of the months of August and January, for the winter and summer, respectively.

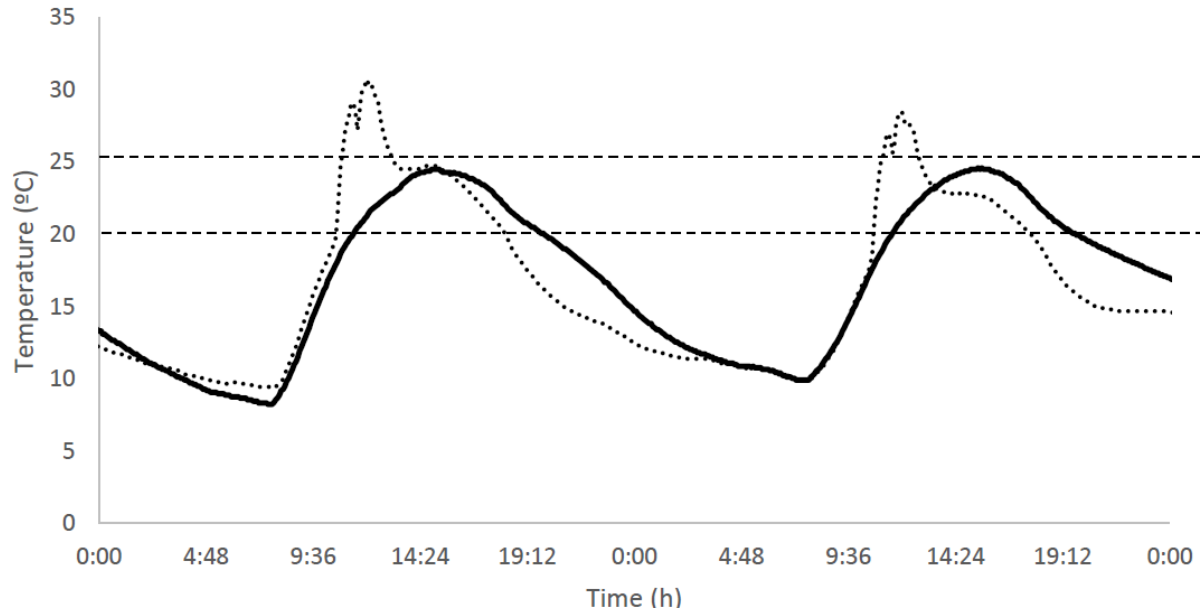


Figure 3. Winter session “—” Internal temperature container with PCM ; “....” Internal temperature container without PCM ; “----” Thermal comfort zone.

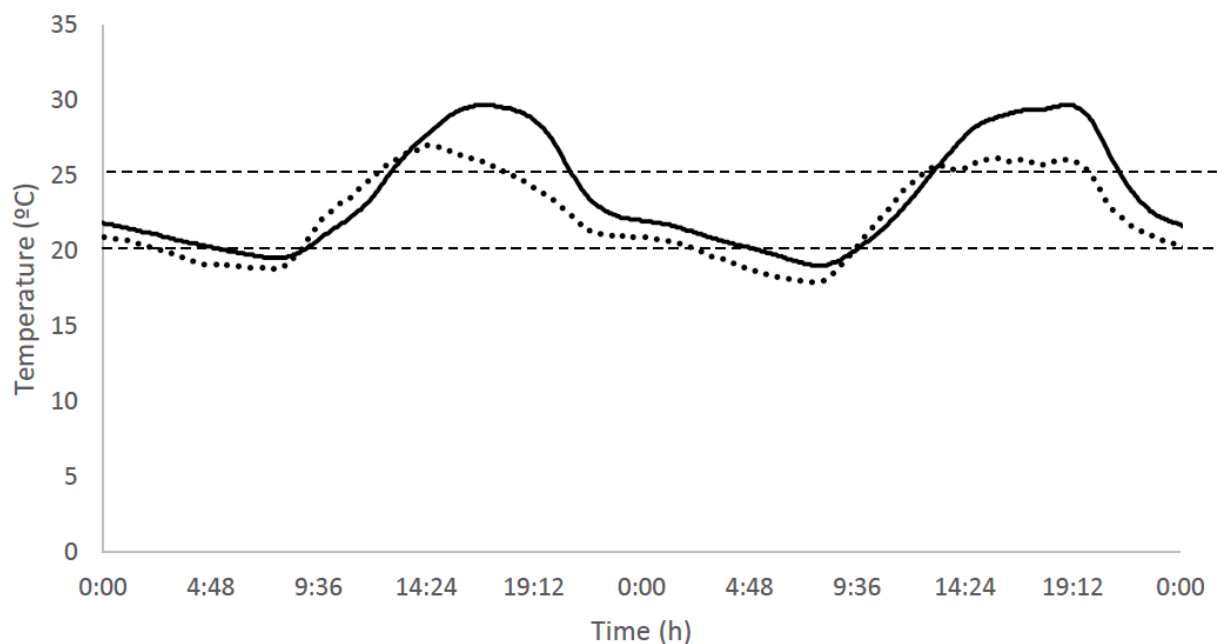


Figure 4. Summer season “—” Internal temperature container with PCM ; “....” Internal temperature container without PCM ; “----” Thermal comfort zone.

Fig. 3 demonstrates that the PCM has a positive effect on the thermal conditioning of the construction, because, this effect allows the daily internal temperature fluctuation to remain longer than container without PCM in the thermal comfort zone. It can also be seen that it causes a thermal delay in the maximum heating loads, occurring in the container with PCM at 15:00 hrs approx., while

for the container without PCM it happens at 12:00 hrs approx. This means that, in case of needing to use an active system such as air conditioning equipment to maintain the sensation of thermal comfort, it will be turned on 4 hours later with the use of PCM, which allows energy savings thanks to the decrease in energy consumption time. In addition to delaying the heating loads, it also decreases them, having a maximum temperature of 30°C approx. without PCM and 24°C with PCM, favoring the reduction of electricity consumption, since in the container with PCM it is not necessary to use any extra active system to keep the interior pleasant, increasing the energy efficiency of the building. The phase change temperature of the applied PCM is 23°C approx., because the temperatures in the northern part of Chile are high, even in the winter season, since one of the main requirements for TES application is that the phase change temperature is within the operating range [4], which in this case is the thermal comfort zone for the northern area of Chile. However, the temperature variation leaves the comfort zone below 20°C, at 18:40 hrs approx. without PCM and at 21:00 hrs approx. with PCM. The effect of maintaining the fluctuation within the area is still denoted thanks to the PCM, which results in energy savings from the use of heaters in a period of 2 hrs 20 min approx. of difference between these results, nevertheless, the cooling loads are not reduced by the effect of the PCM, having a similar behavior to the container without PCM with a minimum temperature of 8°C needing to heat the space from the times indicated in Fig. 3. Analogously to the mining work system, workers with daytime schedule arrive at their rooms to rest at night, while, on the other hand, workers with nighttime schedule were within the limits of the thermal comfort zone during their rest for 11 hours approx. of the 12 hours set, without the need for additional active systems, increasing efficiency and energy savings thanks to the effect of the construction properties in addition to the Comfortboard23.

Fig. 4 shows an overheating in both containers, having maximum temperatures of 30°C approx. with PCM and 26°C approx. without PCM, that is, the construction with common gypsum board shows a more adequate thermal behavior than the building with PCM. It is important to mention that, summer temperatures in this area of the country have minimum temperatures of 20°C approx. during the night, as seen in Fig. 4, therefore, it is presumed that the phase change of the material occurs near the average minimum temperatures of a summer day, attenuating cooling loads, where temperature differences are seen of 1°C between the containers, being the container with PCM warmer and more time in the thermal comfort zone at night. However, when the outside temperature continues to rise, overheating is caused, which may be due to various factors, such as the window, which, from its optical properties generates an increase in the interior temperature, not to mention that, the main disadvantage of lightweight construction is its low thermal mass and low thermal inertia, that put interior comfort at risk due to effects such as overheating [10]. Moreover, when fulfilling its charging period, the PCM release the stored energy when the outside temperature is close to its phase change temperature. Therefore, partially, the overheating could be attribute to the PCM, since, as can be seen in Fig. 4, the Comfortboard23 performs the thermal cycles correctly, which is why the temperature fluctuations with PCM have greater thermal inertia than without PCM. Consequently, it is stated that the phase change temperature (23°C) for the summer season is not the most appropriate. However, it is the phase change temperature that presents the best results in its analysis during the whole year.

Hence, there is no PCM that presents a perfect annual behavior, due to the variation of temperature that is experienced daily in the whole world with different seasons of the year. A combined active/passive system with PCM is recommended as suggested in [13], with the appropriate modifications for this case, improving the application of Comfortboard23 in this type of construction.

Some possible independent solutions are added in the particular case of summer, such as a possible application of PCM in the window, since it is an important factor due to the effect of solar radiation through translucent materials, in addition to the use of active systems with adequate energy expenditure to regulate the sensation of thermal comfort. On the other hand, applying a PCM with a higher phase change temperature according to summer is a possibility, anyhow it is of greater relevance to consider an average annual temperature that presents the greatest benefits to the building, and that is in the corresponding operating temperature, as in this research.

4. Conclusions

The gypsum board Comfortboard23 containing commercial organic PCM with a phase change temperature of 23°C approx. applied as an LHTES system in lightweight constructions similar to those used in mining camps has important benefits in the winter period, prolonging the sensation of thermal comfort, reducing the time and consumption of energy expenditure, improving energy savings and energy efficiency in buildings installed in Antofagasta, Chile. Temperature differences of 5°C are identified between the container with and without PCM in the comparison of the thermal behavior, showing the benefits granted. On the other hand, in summer, the temperature difference in the thermal behavior analyzed is 4°C, the container without PCM showing a better performance due to the phase change temperature of the material with respect to the variation of the external temperature of the area studied, in addition to the construction properties and low thermal mass that contribute to an overheating effect under these operating conditions.

Taking into consideration the thermophysical, optical and physical properties of construction materials is important to determine and carry out an adequate application of TES technologies in constructions, because, these parameters indicate how the building would behave in front to the different thermal loads (internal and external). Besides, knowing the environmental conditions and climate of the geographical area where storage systems are applied is important, since, from solar radiation, the angle and solar height can determine the best location and orientation of the building with PCM and/or another storage system, and if already installed, it allows to understand and improve the thermal behavior that it presents.

The results of the containers analyzed allow to affirm that the application of phase change materials in mining camps would present significant improvements in the use of energy resources in Chilean mining, increasing energy efficiency and energy savings, in relation to use of energy needed for domestic cooling and heating, in addition to providing a nice, pleasant and appropriate rest to workers in the mining area of northern Chile.

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